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ANALYSIS OF ENVIRONMENTAL NOISE MONITORS.(U)

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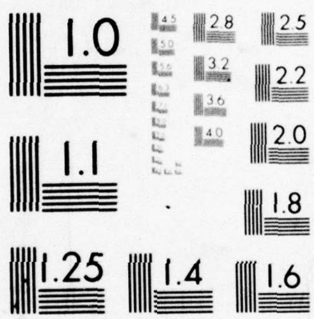

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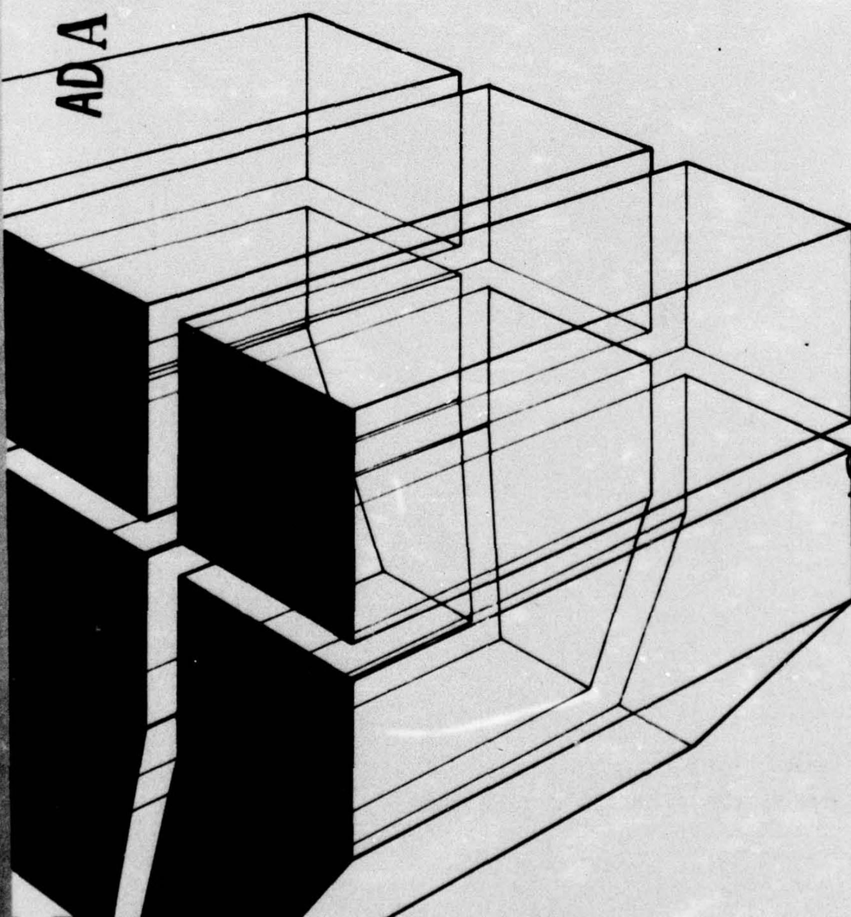
April, 1977

ANALYSIS OF ENVIRONMENTAL NOISE MONITORS



by
P. D. Schomer
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CERL

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This report establishes criteria and performance guidelines desirable in environmental noise monitors that are achievable through state-of-the-art technology. To assess this technology, the performances of 10 available units were evaluated based on the following points:

1. Data reduction methods and analytic results, → Next Page

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2. Dynamic range,

3. Impulse response,

4. Environmental considerations (temperature extremes and wind),

5. Shock resistance,

6. Ease of operation, AND

7. Likelihood of errors in operation.

Favorable and unfavorable features discovered during the investigation of these units are discussed, as well as desirable features found to be absent in all of the units. Based on the study and the conclusions, the operating characteristics of an ideal unit are recommended.

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FOREWORD

This research was conducted for the Environmental Protection Agency's Office of Noise Abatement and Control (EPA-ONAC) by the Acoustics Team (ENA), Environmental Division (EN), U. S. Army Construction Engineering Research Laboratory (CERL). The work was performed under IAO EPA-IAG-D5-0645. Mr. A. Konheim was the EPA-ONAC project coordinator.

COL J. E. Hays is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director. Dr. P. Schomer is Chief of CERL-ENA, and Dr. R. K. Jain is Chief of CERL-EN.

CONTENTS

ANALYSIS OF ENVIRONMENTAL NOISE MONITORS

1 INTRODUCTION

Purpose

The purpose of this report is to establish criteria and performance guidelines desirable in environmental noise monitors that are achievable under state-of-the-art technology.

Approach

To assess this technology, the U. S. Army Construction Engineering Research Laboratory (CERL) tested and evaluated the performance of 10 available systems based on the following points:

1. Data reduction methods and analytic results
2. Dynamic range
3. Impulse response
4. Environmental considerations (temperature extremes and wind)
5. Shock resistance
6. Ease of operation
7. Likelihood of errors in operation.

The tests included both an electrical and acoustical description of the monitors, and a description of their physical and operational characteristics. A set of performance guidelines was developed from this analysis and from the application of technologically related concepts.

This report examines favorable and unfavorable features discovered during the investigation of the 10 units, as well as desirable features found to be absent in all of the units. Based on this discussion, conclusions have been drawn regarding the desirable features to be required of an environmental noise monitor.

Chapter 2 is a general discussion of these points, and Chapter 3 provides details about the individual units. Chapters 4 and 5 give conclusions and recommendations.

Table 1 lists the monitors actually tested, and the appendix summarizes the test results for the individual units. It should be noted that not all monitors available at the time of the study were tested; only those which CERL could obtain readily were analyzed. In addition, none of the monitors introduced since 1975 were studied.

2 GENERAL CONSIDERATIONS

Environmental noise monitoring equipment ranges from simple integrating sound level meters (CERL unit) and simple statistical distribution analyzers (B&K 166) to sophisticated monitoring systems with field readout (Metrosonics, General Radio, or CERL 260) or with laboratory readout (B&K SP321).

Data Collection and Reduction

Three basic philosophies of data collection are evident. One is to save the actual time history of the noise sample on magnetic tape; the data can then be played back and analyzed by several different methods. However, much tape and its attendant bookkeeping are required, and the operator must change the tapes daily if a one sample/second rate is used.

A second method of data collection involves processing the noise data as they are collected, so that the desired information is available in the field. This method is valuable for noise mitigation, since the effects of changes in the noise environment can be measured readily. Furthermore, problems with the unit can be discerned earlier. These units have internal hardware or microprocessors for processing the data, and the type of data developed by the monitor is consequently more difficult to modify.

Lesser used option, employed by the CERL/EPA unit, stores reduced data on magnetic tape. Using a programmable calculator simplifies data format modification, but problems with magnetic tape drives and programmable calculators in the field may occur (see Chapter 3).

The data collected by the various units form a large set which includes the following:

1. Equivalent sound level (L_{eq})
2. Day and night level (L_{dn})

Table 1
Units Tested[1]

Manufacturer	Type	Model Number
B&K Instruments, Inc. 5111 W. 164th St. Cleveland, OH 44142	Environmental Noise Classifier	166
B&K Instruments, Inc. 5111 W. 164th St. Cleveland, OH 44142	Digital Data System for Noise and Vibration	SP321
Computer Engineering Limited (CEL) Cadwell Lane Hitchin, Herts., England SG405J	Noise Average Meter	112
CERL P. O. Box 4005 Champaign, IL 61820	True RMS Integrating Environmental Noise Monitor and Sound Level Meter	260
CERL/EPA[2]	–	–
Digital Acoustics, Inc. 1415 E. McFadden, Suite 1 Santa Ana, CA 93705	Incremental Noise Data Acquisition Unit	DA603
General Radio (GENRAD) 300 Baker Ave. Concord, MA 01742	Community Noise Analyzer	1945
Laboratory Equipment, Inc. 350 Sunset Blvd., N. Renton, WA 98055	Digital Acoustical Data Acquisition System	2010B
Metrosonics Box 18090 Rochester, NY 14618	Sound Level Analyzer	dB-602
Tracor, Inc.[3] 6500 Tracor Lane Austin, TX 78721	Environmental Noise Monitor (Experimental; for internal use only)	–

[1]*Note: Not all monitors available at time of study were tested; only those readily obtainable were analyzed. None of the monitors introduced since 1975 were analyzed.*

[2]This unit is a monitoring package assembled by CERL from commercially available parts.

[3]This unit was experimental and for internal use only. It was rented to CERL for the tests in order to assist in the search for desirable and/or undesirable features.

3. **Standard deviation of the sound pressure (S.D.)**
4. **Noise Pollution Level (NPL)**
5. **Arbitrary L_n values, where n is the percent of time that the L_n sound level is exceeded**
6. **Selected L_n values**
7. **Data bins, which contain the number of times that the sound level falls between two limits**
8. **Department of Housing and Urban Development (HUD) levels, which are specific L_n levels used in HUD criteria**
9. **Sound Exposure Level (SEL)**

10. Community Noise Equivalent Level (CNEL)

11. Single Event Noise Exposure Level (SENEL)

12. Hourly Noise Level (HNL).

Table 2 summarizes the data collection and analysis methods of the various units tested.

Dynamic Range

A noise environment can range from a quiet farm field to a noisy highway or airport. Signals can range from the continuous drone of a distant highway, an industrial plant, or a transformer, to highly impulsive sounds such as those from helicopters, jackhammers, or pile drivers. In the extreme, the monitor may be called on to handle individual, large-amplitude impulses such as those resulting from explosions or sonic booms. The impulsive type of signal adds an additional requirement to the system, since its peak amplitude is far above its root mean square (RMS) value. Thus, the total system dynamic range must extend from the lowest RMS level to the highest peak level required.

Quiet fields will typically exhibit A-weighted sound levels ranging from 30 to 40 dB. Nearby jet planes, helicopters, construction activities, trains, rifle ranges, etc., may exhibit A-weighted sound levels as high as 110 to 120 dB. Because of the impulsive nature of some of these sources, the peak amplitude is likely to be 10 to 20 dB higher than the RMS level of 120 dBA. Thus, the range encountered may even exceed 100 dBA.

Moreover, it is not unreasonable to hypothesize numerous situations in which the L_{dn} could vary signifi-

Table 2
Data Collection and Reduction Characteristics of the Units

Manufacturer	Data Storage	Calculation	Reduced Results Available
B&K 166	CNTR	None	Data Bins
B&K SP321	MT	PC	L_{eq}, NPL, S.D., Arbitrary L_n values
CEL	IM	IC	L_{eq}
CERL 260	IM or PC	IC or PC	L_{eq}, SEL
CERL/EPA	MT	PC	L_{eq}, L_{dn}, S.D., Selected L_n, Data Bins
Digital Acoustics	MT	PC	L_{eq}, NPL, S.D., Selected L_n
General Radio	IM	IC	L_{eq}, L_{dn} Selected L_n, HUD levels
Laboratory Equipment	MT	MC[1]	L_n, L_{eq}, HNL, L_{dn}, NPL, SENEL, CNEL
Metrosonics	IM	IC[2]	Arbitrary L_n values in 1-dB steps
Tracor	MT	MC[1]	L_{eq}, CNEL, Selected L_n

[1]At manufacturer's facility.

[2]The stored data can be read by a Wang 600 programmable calculator for further processing.

KEY:

MT = Magnetic Tape
CNTR = Mechanical Counter
IM = Internal Semiconductor Memory
PC = Programmable Calculator
MC = Minicomputer
IC = Internal Calculator

cantly from one day to the next; for example, on one day, the 30-dB threshold would be important, and on the next, the peak amplitude requirement would be important. Examples of this situation would be a construction activity that closes for the weekend, an airfield where runway usage changes with the winds, or a local gun club used only on the weekends.

The first element to be considered in determining the dynamic range is the microphone. A 1-in. (25 mm) condenser microphone typically ranges from a lower A-weighted limit of 18 to 20 dB to approximately 130 to 140 dB. Typically, the 1/2-in. (13 mm) condenser microphone raises these limits by approximately 10 dB, so the lower and upper A-weighted limits are approximately 30 dB and 150 dB, respectively. When considering flat-weighted signals, the noise floor of the microphones rises 7 to 10 dB; the resulting floor is approximately 25 dB flat-weighted sound pressure level for a 1-in. (25 mm) microphone, and approximately 40 dB flat-weighted for a 1/2-in. (13 mm) microphone.

In addition to the sensitivity limitation of the microphone, there is the limitation created by wind noise. A moderate wind, such as 12 mph (19 km/hr), will produce a noise level of approximately 45 dBA when a microphone is used in conjunction with a standard windscreen.

The microphone is also limited electrically. The low-level electrical signals produced by any of the microphones near their low-level limits typically range from 20 to 30 μV for the condenser microphones and even lower for other microphones such as electret and piezoelectric. At these low levels, it may be necessary to amplify the microphone signal before it is sent by cable from the microphone to the monitor proper. In some instances, low-noise cables, short cables, or rigid connection between the microphone and monitor may be sufficient.

At times, other factors may dominate. For example, with sensitive microphones, wind noise generated at the microphone may be greater than wind noise translated into electrical noise by motion of the cable in the wind; however, the opposite may result for less sensitive microphones. A rational approach is to treat the microphone system as a whole (the microphone element and its associated limitations, the windscreen, wind noise, cable noise, preamplifier noise, and signal amplifier noise at the microphone) and discuss the overall dyanamic range which must be present at the end of the cable connecting into the monitor proper. Because the microphone system elements and the overall microphone system response are being studied by the National Bureau of Standards, only the required overall performance is given here. The ideal performance would be capable of extending down to an A-weighted noise floor of about 35 dB. The peak RMS amplitude capability should be such that the lowest voltage from the smallest acoustical signal is 5 to 10 dB above the input noise of the monitor when its input is short-circuited.*

The dynamic range of the monitor, which is an electrical quantity, must be such that the noise floor is below the lowest level signal sent by the microphone system and yet capable of accepting the highest level signal sent by the microphone system.

Impulse Response

Like dynamic range, impulse response is a key parameter of the microphone system and environmental noise monitor, and like dynamic range, there is a wide set of requirements for impulse response. Impulsive noise sources are not limited to military sources, such as artillery, armor, or rifle fire, but also include numerous sources in built-up urban areas, such as quarries, railroad marshaling yards, gun clubs, forging plants and other similar industrial activities, and quasi-continuous impulse sources such as helicopters, jackhammers, and pile drivers. For many of these sources, and especially for the isolated events, the quantity measured is actually the impulse response of the monitoring or measuring equipment, rather than a distinct characteristic of the noise source. Direct integration offers a good means to eliminate the vagaries of meter impulse response from the measurement system.

Field Use

Field use includes environmental considerations and shock resistance. It is easy to hypothesize temperature, weather, and shock resistance extremes, which can affect field use as much as the electrical extremes placed on dynamic range and impulse response. CERL has monitored highway noise over temperatures ranging from -20°C (-40°F) to 40°C (104°F) without electrical power available. Other monitoring situations have ranged from a suburban front yard, for which the equipment was driven to the site in a standard sedan,

*This requirement assumes that a low impedance source is used to drive the cable. If a high impedance source is used to drive the cable, then input noise of the monitor must be measured with this impedance across the input rather than a short circuit.

to large, remote construction sites, for which the equipment was transported roughly to the site in the back of a pickup truck. Weather conditions have ranged from bright sunshine and light wind to snow and ice storms, thunderstorms, and tornado-like winds. Humidity extremes have ranged from 10 to 100 percent relative humidity.

Operational Considerations

Operational considerations include ease of operation; likelihood of errors during operation of data reduction; manpower considerations, such as number of personnel required to set up and calibrate the equipment; hours required for data reduction; and other time considerations.

3 RESULTS OF TESTS AND ANALYSIS OF THE MONITOR UNITS

Dynamic Range

As discussed in Chapter 2, the dynamic range of the monitoring system (an electrical quantity) must have a noise floor below the lowest signal sent by the microphone system but also be capable of accepting the highest level signal sent by the microphone system. When these two systems are not properly aligned, a resulting loss in dynamic range can be expected. For example, if the lowest signal transmittted to the monitor by the microphone system is 10 μV and the input noise of the monitor is 1 mV, then 40 dB of range would be lost. Similarly, if the largest voltage the microphone system may transmit to the monitor is 100 V, but the monitor clips those signals in excess of 10 V, then 20 dB of potential dynamic range would be sacrificed.

Some of the systems tested by CERL exhibited this difficulty. Although the electrical dynamic range of the instrument was adequate, it could only be realized when using the monitor in conjunction with specific microphones. For example, one unit had a dynamic range of 120 dB using a 1-in. (25 mm) condenser microphone, but only a 61-dB dynamic range when using a very insensitive microphone. Some units accommodated partially or fully for various microphone system capabilities by including input range switches. For example, it may be possible to attenuate a signal from a microphone so that it is not clipped by the monitor, but it may not be possible to amplify a low-level signal without the resultant clipping of the high end of the signal and the consequent reduction in the dynamic range.

Based on the data for the individual units tested, the dynamic range of available units ranges from a low of 30 dB to a high of about 120 to 125 dB, with typical values between 75 and 100 dB. Table 3 lists the optimum dynamic range of the various units along with corresponding microphone systems. Use of other microphone systems may decrease the dynamic range. Thus, current monitor systems will meet, or almost meet, system dynamic range requirements when they are used with optimum or nearly optimum microphone systems.

It was found that the calibration potentiometer may alter the dynamic range in some units, but this is usually not a problem when the optimum microphone is used.

The overall dynamic response of the monitor system is a function of (1) the dynamic range of the electrical characteristics of the monitor, (2) the overall dynamic range of the microphone system, and (3) the match between the microphone system and the monitor itself. For accuracy, the monitor system dynamic range should be specified for each microphone system that the manufacturer intends it to be used with. In addition, the electrical dynamic range, maximum input voltage, and noise floor should be specified. When the calibration potentiometer alters the dynamic range, the manufacturer should specify the minimum range which would be obtained under a "worst case" calibration potentiometer setting.

Impulse Response

All units were tested for their capability to handle grossly nonsinusoidal wave forms. A method was devised to test the electrical characteristics of the monitor systems: a sine wave was fed into a tone burst generator and the gating of the generator was arranged to produce one cycle of the sine wave followed by arbitrarily long, blank intervals before the next sine wave. This waveform produced signals with a wide range of crest factors. Additionally, when the gating was set for a long time between impulses, it was possible to test the response of the unit to infrequently occurring signals. Since the RMS value of the sine pulse can be calculated theoretically, the theoretical and actual readings can be compared. This test shows whether a detector has true RMS characteristics.

Table 4 shows the results of the sine pulse test with the different monitors. The B&K 166 was not tested, since it has an unusual display and is sampled infrequently. For comparison, a B&K 2209 sound level

Table 3
Dynamic Range of Units Tested

Instrument Range	Weighting Available	Maximum Reading (dB)	Dynamic Range[1] (dB)	Maximum Input[1, 2]	Noise Level[1, 3]	Microphone Sensitivity Relative to 1 V/Pa (dB)
B&K 166						
60-dB range	A, C, D, Flat	90	30	5 mV	–	–50
B&K SP321						
35-dB base (cw)[4, 5]	A or Flat	95	71[6]	110 mV	30 μV	–20
35-dB base (ccw)	A or Flat	95	72[6]	40 mV	10 μV	–29
65-dB base (cw)	A or Flat	125	71[6]	340 mV	96 μV	–29
CEL						
Microphone high	A	147	77	1.2 V	170 μV	–51
Microphone low	A	117	75	38 mV	6.8 μV	–51
Auxiliary	Flat	147	77	7.1 V	1 mV	–35
CERL 260						
Microphone	A, C, D, Flat	102[7]	96	10 V	.16 mV	–8
CERL/EPA						
120 dB scale[9]	A, C, D, Flat	120	80	10 V	1 mV	–10
DIGITAL ACOUSTICS						
Calibration switches						
minimum	A or Flat	143	123	12 V	8.5 μV	–27
maximum	A or Flat	143	61	8.9 mV	7.5 μV	–90
General Radio						
Microphone	A, C, Flat	120	98	.13 V	1.6 μV	–44
Auxiliary	A, C, Flat	120	98	.51 V	6.5 μV	–32
Laboratory Equipment[11]						
Microphone	A, C, Flat	125	100	1.8 V	18 μV	–26
Metrosonics						
130 dB (cw)[12, 5]	Flat	149	87	4.38 V	.20 mV	–26
130 dB (ccw)	Flat	149	99	26.5 V	.30 mV	–42
Microphone A (cw)[13]	A	119	87	.18 V	8 μV	–40
Tracor						
130 dB range	A	129	85	.36 V	20 μV	–44
100 dB range	A	99	69	11 mV	4 μV	–44

[1] Linear weighting used wherever possible.
[2] Maximum input refers to voltage in at maximum reading.
[3] Noise level refers to calculated voltage at the lowest value the display will read with the input shorted.
[4] For 1-in. (25 mm) position. In 1/2 in. (12.5 mm) position, base and readout are 10 dB higher.
[5] (cw) and (ccw) refer to the position of the calibration potentiometer.
[6] Only 60 dB is actually used in basic system.
[7] Up to 80-dB correction factor can be added.
[8] –29 dB with 20 dB of gain in B&K 4921 and 17 dB of correction.
[9] Any scale may be entered from the keyboard.
[10] With 18.5 dB of gain in a B&K 4921, the microphone sensitivity is –29 dB.
[11] From manual–unit not tested.
[12] Range switch only changes displayed value.
[13] Microphone B same as Microphone A, but display reads 10 dB higher. Microphone inputs have 30 dB preamp.

Table 4
Sine Pulse Tests of the Monitors

Fundamental = 1 kHz **n = Period in msec**

Manufacturer	n=1	n=2	n=5	n=10	n=50	n=500	n=5000
Theoretical RMS relative square wave of 0 dB	−3 dB	− 6 dB	−10 dB	−13 dB	−20 dB	−30 dB	−40 dB
B&K 2209 SLM[1]	−3	− 6	−10	−13	−20		
B&K SP321[2]	−3	− 6	−10	−13	−20	−27	
CEL	−3	6	−10	−13	−20	−30	−39
CERL 260	−3	− 6	−10	−13	−20	−30	−40
CERL/EPA[1]	−3	− 6	−10	−13	−38		
Digital Acoustics[3]	−3	− 6	−19	−12.9	−19.8 to −20.5	−28.5 to −31.5	−50
General Radio[2, 1]	−3	− 6	−10	−13	−20		
Metrosonics[4]	−3	− 7	−10	−42			
Tracor[5]	−4	−10	−18	−29	−44		

[1]Crest factors at least 14 dB at maximum reading.
[2]When n is 500, display values change rapidly, making accurate reading impossible.
[3]Crest factor at maximum depends on calibration switch setting. On most sensitive setting, crest factor is 3 dB and improves as the sensitivity is reduced.
[4]Crest factor is 10 dB at maximum signal input.
[5]The Tracor unit has an averaging detector rather than an RMS detector.

meter was also tested. The table shows that the CEL and CERL 260 units can handle impulses separated by a considerable amount of time without giving erroneous results. Since all tests were run on the fast position of the detectors, most of the other units encountered difficulties with the wide spacing because of the detector time constant used in the RMS detectors. These time constants are approximately 100 msec except for the CERL/EPA unit. The Tracor unit shows clearly what happens when an averaging detector is used rather than an RMS detector. The B&K 2209 sound level meter, by comparison, works well until an n reading of 500 is reached, at which point the needle jumps with every pulse; the jumping of the needle then becomes the limiting factor.

Similar measurements made using 10 kHz and 100 Hz rather than the 1 kHz oscillator frequency tended to confirm the inability of certain detectors to operate above various crest factors, since test results would change if the difficulty were a sampling rate problem and not a detector problem. For example, with n equal to 500, the oscillator at 1 kHz, a detector with a 100-msec integration time, and a sample rate of 1 per second or slower, the fast decay of the integrator might result in missing the peak if an exact beating occurred. Raising the oscillator frequency to 10 kHz eliminates this possibility.

Analytic Results

Chapter 2 discussed the basic philosophy of location of data reduction and type of data available. Here, the availability of an analog data output and specific analytic results are compared.

Of the units tested, three had a specific output jack for taking tape recordings. The CERL/EPA, the CERL 260, and the Digital Acoustics units had output jacks that would conveniently supply the signal to a tape recorder. The Digital Acoustics unit also had an auto-ranged output which allowed an inexpensive recorder to be used over the full dynamic range of the unit. The other units required that the operator arrange for his/her own T-connection to take the signal from the microphone to the tape recorder. Two units–the Tracor and B&K 166–did not have this capability, since the microphone was integral to the unit.

Specific analytic results were compared by means of a test tape which was prepared by placing a microphone approximately 50 ft (15 m) from a busy roadway. This tape was approximately 1 hour long and was played into all the instruments tested. Table 5 summarizes the L_{eq} results for the various instruments capable of measuring it. This table also shows L_{eq} results measured by the CERL 260, which has a purely digital detector and employs no time constant in the RMS detection circuit. As can be seen from the table, the L_{eq} values do not vary more than ± 1 dB from one unit to another with the exception of the Tracor unit, which is in error, because the unit employs an average rather than an RMS detector. It should also be noted that the CEL and CERL 260 units, which are the only units having true RMS direct integration detectors not employing any time constant, record identical values.

Table 5
Measured L_{eq} on Traffic Noise Test Tape

Manufacturer	Flat L_{eq}	Sample Rate
B&K 166[1]	98.9	1/sec
B&K SP321	100.3	10/sec
CEL	99.00	Variable frequency digital integrator
CERL 260	99.0	50 kHz continuous integration
CERL/EPA	98.1	10/sec
Digital Acoustics	98.8	1/sec
General Radio	100.0	10/sec
Metrosonics[2]		1/sec
	A L_{eq}	
CERL/EPA	92.1	10/sec
Tracor[3]	89.0	1/sec

[1]Values were computed by hand from raw data.
[2]This unit did not have the L_{eq} option installed.
[3]Tracor unit is not directly comparable to others. When using the direct electrical input, the response is somewhat flatter than A weighting.

The L_1 and L_{50} results from the units capable of supplying these data were also compared. Table 6 summarizes these results. Considering the CERL 260 as the "standard" because of the close agreement between the CEL and the CERL units on the L_{eq} measurement, it is apparent that the L_1 values in the table are generally in close agreement with the value obtained by the CERL 260, although they are sometimes somewhat above it. Similarly, for the L_{50} values, the recorded data are usually above this value, with the exception of the CERL/EPA unit, which is somewhat below it. The Metrosonics unit tested in this study, which did not measure L_{eq} (although it has this capability with a separate option), agreed with the CERL 260 measurements.

Operational and Environmental Considerations

This discussion is divided into three parts: (1) general difficulties encountered with the various units, (2) results of temperature variations, and (3) data reduction time requirements.

Table 6
Measured L_1 and L_{50} Levels of Traffic Noise Test Tape

Manufacturer	Sample Rate	L_1	L_{50}
		Flat Weighted	
B&K 166[1]	6 sec/sample	108.5[2]	97.5
B&K SP231	1/sec	110.7	96.7
CEL[3]	Integrator		
CERL 260	10/sec[4]	109.0	95.0
CERL/EPA "flat" weighted	10/sec	110.2	97.2
Digital Acoustics	1/sec	112.0	97.2
General Radio	10/sec	110.0	96.0
Metrosonics	1/sec	109.0	95.0
		A Weighted	
CERL/EPA	10/sec	105.7	83.7
Tracor[5]	1/sec	96.0	87.0

[1]Values were computed by hand from raw data.
[2]This is the value of the highest bin.
[3]This unit calculates only L_{eq}.
[4]Each sample was the sum of 5000 readings taken at a 50-kHz rate.
[5]Tracor unit is not directly comparable to others. When using direct electric input, the response is somewhat flatter than A weighting.

General Difficulties

Investigation of the various available noise monitor units revealed numerous difficulties in their setup and operation, ranging from cabling to setting of controls to data readout. The following sections discuss difficulties encountered with the various units and the requirements to be incorporated into an ideal unit.

Most of the outdoor units tested required the cover to be open to operate the controls and to read data out. However, no provision had been made to weatherproof the internal controls and readout, which is particularly bad if magnetic tape must be changed or the units calibrated in the rain. It is impossible to check the operation of some units while they are running, so it is not always known whether the unit has stopped or whether it is operating properly.

Most of the units used light emitting diodes (LED) to give the operator numerical information. Since these LEDs are hard to read in sunlight, some means of protecting the display from excessive light levels is required.

Following are specific deficiencies noted in the units tested:

1. B&K Model 166 Environmental Noise Classifier. One of the main disadvantages of this unit is that it requires 110-V power for operation. In addition, all of the individual counter readings must be recorded; however, these counters are mechanical, so they are much easier to read than the LED displays. Resetting the counters to zero is also a problem, because as some of the counters are reset, others are gathering data; therefore, when one reaches the end, the counters that were reset originally have already accumulated new data. This unit lacks a master reset button, so the only easy means of resetting the unit is by turning off the power.

2. B&K SP321 Noise Monitor System. The B&K SP321 is designed to be used outside, but not with the B&K 4921 outdoor microphone system. Two external 12-V batteries are required to power the SP321 when using the 4921. Moreover, calibrating the SP321 with the 4921 is ambiguous; there can be a 10; 20; or even a 30-dB error in the calibration procedure, because the ten's digit is lacking in the display. In addition, the tape unit employed for data storage in the SP321 froze in less than half a day during cold temperature testing; however, the major difficulty was moisture rather than lack of a cold temperature tape. In general, it was found that information read back by the tape was unreliable, perhaps indicating a basic problem in either the recording or the reading process.

3. CEL Noise Average Meter. Although not an environmental noise monitor, the CEL Noise Average meter was evaluated, since it was sufficiently different from other sound level meters. The major difficulties with this unit are (1) that calibration is difficult because of the time required to obtain a reasonable equivalent level, (2) the unit has only limited battery life and cannot be used in the field for an entire day, and (3) the Nixie tube display is harder to read in direct sunlight than the LED display.

4. CERL 260. This unit has only L_{eq} and SEL available in the field. It is necessary to use a programmable calculator if statistical data are required. The unit is heavy, but can be carried by one person. The unit is weatherproof, like the B&K SP321, and the front panel is also waterproof, so the controls can be accessed in bad weather. Also, the unit does not have to be opened to output data, since the digital printer can be used to give a start print command. The memory can be cleared to make room for new data as the old data are printed.

5. CERL/EPA Noise Monitoring System Employing the Wang Computer Calculator. The CERL/EPA unit is very bulky, requiring two persons for setup and disassembly. Moreover, the unit is designed only for 110-V power and only for sheltered use. The Wang calculator is sensitive to power line spikes and occasionally stops program execution. The requirement for sheltered operation places an additional limitation on the unit's monitoring flexibility. The unit with the Wang computing calculator is rather complex to operate, requiring numerous entries in a precise order. Because of the Wang's limited alphanumeric memory capability, no prompting is available from the calculator, so a "crib" sheet must be used to insure that operational setup parameters are entered in the proper order and manner. Similarly, interpreting the output data is difficult because only a few identifiable letters are available, rather than the complete labels. Again, use of an external "crib" sheet is required to interpret the data output. The unit's RMS detector requires a 20-min. warmup time. The screw-type connectors used to attach cables to the unit are prone to difficulties, because nicks in the connectors impede their operation.

6. Digital Acoustics Noise Monitor System. This unit possessed only minor difficulties. The unit is designed to work with a wide range of microphones; how-

ever, changing from one microphone to another requires a complete stripdown of the unit to set tiny internal switches placed on printed circuit boards which set up the gain for different microphones.

7. General Radio (GENRAD) Environmental Noise Monitor. The GENRAD Environmental Noise Monitor had several minor problems which did not impede overall operations or increase error possibilities, but which should be considered. The unit is designed with a microphone at the end of a 5-ft. long (1.5 m) pole attached to a case. The monitor is inside this case; it is difficult to ship this unit due to the shape of the case and the long pole attached. In addition, the instability of the case without its electronics inside makes the unit prone to falling over, as when the batteries are charged. The case is not airtight, so there is potential for moisture condensation on the components inside. The only readout capability is through LED display on the front panel, which means that the operator must record the data accurately—an unpleasant task, especially in cold weather. The LED display is difficult to read in bright sunlight. The calibration potentiometer is difficult to adjust, requiring a long, thin screwdriver since it is recessed approximately 4 in. (102 mm) below the panel surface. Additionally, changing weighting networks requires a screwdriver rather than a knob; this operation is particularly difficult in cold weather when the operator must wear gloves. The GENRAD unit is powered by internal "D" cells, which last approximately 3 days. The arrangement of the battery compartment makes changing the batteries very difficult; also, the batteries cannot be changed while the unit is operating.

8. Laboratory Equipment Environmental Noise Monitor. This unit was not tested because it malfunctioned and was returned to the manufacturer for repair.

9. Metrosonics Noise Monitor. This unit had only very minor problems: use of the screw connector rather than the bayonet connector, the necessity of writing down data rather than having a data readout system, and the use of the LED display which is sometimes difficult to read in bright sunlight.

10. Tracor Corporation Environmental Noise Monitor. Like the CERL/EPA unit, this unit was bulky (although one person could move it) and used the screw-type connectors. This unit had a paper tape chart recorder that was difficult to change, especially in cold weather; also, the paper advance mechanism and the magnetic tape froze during the cold weather test. The calibration procedure was extremely difficult, requiring two persons. The unit's microphone was attached and was designed only for mounting on a heavy pole (such as a telephone pole), rather than having flexibility in its area of placement. This unit could not be opened by latches, but instead required the use of a large screwdriver.

Temperature Testing

The units were subjected to temperature extremes to test their capability to withstand different temperature conditions. The extremes ranged from -12°C (11°F) (the lowest controlled temperature available) to approximately 50°C (122°F) (representative of the approximate temperature inside a van on a hot summer day). In actual use, the units clearly presented a number of problems. For example, the paper chart recorder on the Tracor unit was very difficult to change in the cold temperature. Also, as indicated earlier, the units requiring direct data recording in cold temperatures cause discomfort to the operator.

Other cold temperature problems were mechanical in nature. The tape unit on the B&K SP321 froze due to moisture condensation on the tape mechanism, and the chart recorder on the Tracor unit froze. Also, the batteries of all the battery units exhibited lower capacity during the cold temperature test, and none met the values given in the manufacturer's data sheets. As a safety factor for presently manufactured units, the user should divide the stated battery capacity by two when operation is planned below 0°C (32°F). The appendix summarizes power requirements and battery capability for each unit.

All outdoor units other than the General Radio and Laboratory Equipment models operate essentially as sealed units, except when the operator must have access to the controls. Because these two units do have ventilation from outside to inside, rapid changes in temperature will probably cause condensation.

Data Reduction Time Requirements

The length of time required to process a 1-hour block of data varies from 10 minutes for a B&K SP321 unit to direct readout for the CERL 260 unit. Analysis time for the B&K 166 is determined by how rapidly numbers on a form provided by the unit's manufacturer can be computed. However, the calculations are subject to arithmetic errors which, when they occur, cause the remaining L_n values to be in error. The data reduction speed of the General Radio and Metrosonics units depends on how fast the operator can write down the numbers displayed. The processing time of the remaining units does not vary greatly, but the amount of computor effort required differs appreciably. The Digital Acoustics and CERL/EPA units can be set to run continuously to process a full data tape without stopping. The B&K SP321 unit requires the operator to enter data for each block requiring a separate printout. The CERL 260 unit can print out all the data in memory (96 blocks) in two minutes on a digital printer.

Table 7 lists the time required to analyze a 1-hour block of data, and reiterates the data shown in Table 2.

Table 7
Data Reduction Time Requirements and Data Storage and Collection Characteristics of the Units

Manufacturer	Data Storage	Calculation	Time to Analyze a 1-Hour Block	Results Available
B&K 166	CNTR	None	–[1]	Data Bins
B&K SP321	MT	PC	4 minutes	L_{eq}, NPL, S.D., Arbitrary L_n values
CEL	IM	IC	Direct Readout	L_{eq}
CERL 260	IM or PC	IC[3] or PC	Direct Readout	L_{eq}, SEL
CERL/EPA	MT	PC	1/2 minutes	L_{eq}, L_{dn}, S.D., Selected L_n, Data Bins
Digital Acoustics	MT	PC	3 minutes[2]	L_{eq}, NPL, S.D., Selected L_n
General Radio	IM	IC	1-1/2 minutes	L_{eq}, L_{dn}, Selected L_n, HUD levels
Laboratory Equipment	MT	MC[4]	–	L_n, L_{eq}, HNL, L_{dn}, NPL, SENEL, CNEL
Metrosonics	IM	IC[3]	1-1/2 minutes	Arbitrary L_n values in 1-dB steps
Tracor	MT	MC[4]	–	L_{eq}, CNEL, Selected L_n

[1]About 10 minutes are required to get selected L_n's and L_{eq} from data in bins.
[2]Time varies with the data sample rate.
[3]The processed data can be read by a Wang 600 programmable calculator for further processing.
[4]At manufacturer's facility.
[5]Time varies with the number of L_n's examined.

KEY:

MT = Magnetic Tape
CNTR = Mechanical Counter
IM = Internal Semiconductor Memory
PC = Programmable Calculator
MC = Minicomputer
IC = Internal Calculator

4 CONCLUSIONS

Results of this research have indicated that none of the currently manufactured monitors tested in this study contain all of the characteristics desirable in an ideal unit.

The L_{eq} appears to be easily measurable, providing uniform results from monitor to monitor.

L levels seem to be rather sensitive to slight differences from monitor to monitor; during testing, it was noted that they can change substantially for two analyses of the same recording with the same monitor.

5 RECOMMENDATIONS

Dynamic Range

The dynamic range of the microphone and its associated power supply, windscreen, amplifiers, and cables to the monitor unit, should be 80 to 100 dB, depending on planned use. For monitoring in quiet areas, the A-weighted noise floor should be about 35 dB. The peak instantaneous amplitude capability should be more than 140 dBA.

The equivalent electrical voltages at the end of the cable of the microphone system where it connects into the monitor should be such that the lowest voltage from the smallest acoustical signal is 5 to 10 dB above the input noise of the monitor.

The analyzer itself should have a dynamic range at least equal to the range of the microphone system. Voltage levels between output of the microphone system and input to the analyzer should be alignable so that there is no sacrifice in dynamic range.

Dynamic range should be specified by the manufacturer for each of the microphone systems recommended for use with its system. Further, when there is a possibility of degraded dynamic range based on the setting of a gain potentiometer, the worst possible case (using the recommended microphone system) should be specified. (The input noise of the monitor should be measured by using an impedance equivalent to the output impedance of the microphone system.) The dynamic range as a straight electrical system should also be specified as well as input noise and maximum voltage. For this specification, the gain potentiometer should be adjusted to yield the maximum dynamic range.

Requirements Which Will Reduce Mechanical Problems

The monitoring system and the microphone system should each be light enough and small enough so that one person can conveniently set up and disassemble the system.

The operation of the system should be such that one person can conveniently turn on, start up, obtain data, and calibrate the system.

The units should be designed for outdoor use. The front panel should be weatherproof so that opening the unit during inclement weather will not adversely affect it. This requirement is especially important when one considers the use of paper tape or magnetic tape for which moisture is a more serious problem, especially at very cold temperatures.

The unit should be particularly designed for cold weather use; switches and other mechanical devices must be designed for operators wearing gloves and other bulky clothing.

Operations should be as simple and straightforward as possible; the front panel design should be easily understood by technicians, and its functional areas should be grouped logically.

The readout device (when digital readout is used) should be easily readable in sunlight. A simple sunshade will enhance reading of the LED and Nixie tube displays.

All necessary controls should be easily accessible and not require the use of extraordinary tools such as long, thin screwdrivers.

Bayonet cable connectors should be used rather than screw-type connectors, since they are less prone to field damage.

Paper charts or magnetic tape should be avoided, if possible, due to the difficulties to these mechanical units caused by dirt and moisture (especially at cold temperatures). Low-cost, solid-state memory is preferable. When mechanical recording devices are used, they must be easily serviceable by technicians wearing gloves and must be especially protected from the elements.

Power Supply Requirements

The units should be capable of extended operation on either internal or external batteries.

The batteries should be easily removable and changeable without impeding operation of extensively used monitors.

A 110-V option should be used only with internal, noninterruptible power supplies.

When using 110-V power, the monitor system should be unaffected by transients and other disturbances on the power line.

Battery life specification by the manufacturer should not only be for laboratory temperatures but also for cold temperature use, i.e., -20°C (-4°F).

Operating Environment

The monitor should be operable in temperatures ranging from -30°C (-22°F) to 50°C (122°F) without adverse effect on its performance.

There should be no great variation in gain, sensitivity, or other performance factors with temperature changes.

Crest Factor and Impulse Handling Capability

To avoid discrepencies between systems, the detector should ideally be a true integrator. That is, the detector and monitor should implement the integral of the square of the weighted sound pressure level as a function of time. If true integration is not employed, the rise and fall time of the standard RMS detector should be specified in detail, including damping requirements, so that results will be comparable from monitor to monitor.

Sampling Rate

When using traditional RMS detectors having inherent integration times, the sampling rate need not be faster than approximately two times the integration rate, or 2T, where T is the integration time.

When employing true integrating detectors, the integrator output should only be sampled at the end of the measurement period. If only L_{eq} hours are required, the sampling of the detector should only be performed hourly.

For the traditional RMS detector, the crest factor should be at least 15 to 20 dB.

Data Output

Data should be available directly on the front panel in a form readable by an operator.

High-speed data output should be provided so that the operator need not record large quantities of numbers. Data recording by hand is an error-prone procedure and can be quite burdensome to the operator in very cold weather. The recording device need not be contained within the monitor proper, but may be carried to the site by the operator.

Monitors performing data reduction in the field, and therefore providing results immediately, are preferable to those requiring subsequent laboratory analysis; in the former, correct operation can be checked on-site and other related work accomplished during the monitoring period.

Calibration

Overall system calibration should be easy to perform by one person.

A remotely operated acoustical calibrator should be built into the microphone system, because system calibration can then be performed without actually going to the microphone.

Single-frequency calibration should take only a few seconds and should not require extended integration periods to achieve sufficiently accurate results.

The system should be capable of calibration in any operating mode and not restricted to use of a certain microphone.

The calibration should be unambiguous for all recommended microphone systems.

Analog Output

An analog output should be conveniently provided for connection to other analog recording devices and to high-impedance headphones. Connecting these devices to the analog output should not affect monitor system performance.

Factory Testing and Packaging

Units should be designed for rough handling and field use in dusty and inclement environments. They should be fully electrically tested, including extended battery operations, prior to shipment.

Prior to electrical testing, the manufacturer should place the unit on a shock test machine set to perhaps 1g at 10 Hz for 2 hours.

The use of military-grade inclosures for the equipment is desirable, since these are intended for strenuous use.

APPENDIX: MONITORS TESTED

B&K Model 166
Environmental Noise Classifier

Data Storage: Mechanical Counter
Calculation: None
Results Available: Data bins
Time to Analyze a 1-Hour Block: About 10 minutes of hand calculation are required to get selected L_n's and L_{eq} from data in bins.
Electrical Inputs: 60-dB range[1]
Weightings: A, C, D, flat
Maximum Readings: 90 dB
Dynamic Range: 30 dB
Maximum Input: 5 mV
Noise Level: –
Equivalent Microphone Sensitivity:
re 1 V/Pa −50 dB
Crest Factor: Not tested due to unusual display
Sample Rate: 6 seconds/sample
Power Supply: 120 V ac
Endurance: –

[1]The ranges available are 45 and 60 to 100 in 5-dB increments.

B&K Model SP321
Digital Data System for Noise and Vibration

Data Storage: Magnetic tape
Calculation: Programmable calculator
Results Available: L_{eq}, NPL, S.D., arbitrary L_n values
Time to Analyze a 1-Hour Block: 4 minutes with data rate 1/second. Lower sample rates require less time and vice versa.

Electrical Inputs:	35-dB base (cw)[1]	35-dB base (ccw)	65-dB base (cw)
Weightings:	A or flat	A or flat	A or flat
Maximum Readings:	95 dB	95 dB	125 dB
Dynamic Range:[2]	71 dB	72 dB	71 dB
Maximum Input:	110 mV	40 mV	340 mV
Noise Level:	30 μV	10 μV	96 μV
Equivalent Microphone Sensitivity: re 1 V/Pa	−20 dB	−29 dB	−29 dB
Crest Factor:	20 dB	20 dB	20 dB
Sample Rate: 1, 3, 10 seconds/sample			
Power Supply:	120 V ac	External power supply	Internal rechargeable batteries
Endurance:	–	–	48 hours

[1]cw and ccw refer to the position of the calibration potentiometer.
[2]Only 60 dB is used in basic system.

CEL Model 112 Noise Average Meter

Data Storage: Internal memory
Calculation: Internal computation
Results Available: L_{eq}
Time to Analyze a 1-Hour Block: N/A

Electrical Inputs:	Microphone high	Microphone low	Auxiliary
Weightings:	A	A	flat
Maximum Readings:	147 dB	117 dB	147 dB
Dynamic Range:	77 dB	75 dB	77 dB
Maximum Input:	1.2 V	38 mV	7.1 V
Noise Level:	170 μV	6.8 μV	1 mV
Equivalent Microphone Sensitivity: re 1 V/Pa	−51 dB	−51 dB	−35 dB

Crest Factor: *3 dB at maximum input; can handle individual events.*
Sample Rate: Variable-frequency digital integrator

Power Supply:	120 V ac		Internal rechargeable battery
Endurance:	–	–	5 hours

CERL Model 260
True RMS Integrating Environmental Noise Monitor and Sound Level Meter

Data Storage: Internal memory
Calculation: Internal computation
Results Available: L_{eq}, SEL
Time to Analyze a 1-Hour Block: *Direct readout*
Electrical Inputs: Microphone
Weightings: A, C, D, flat
Maximum Readings: 102 dB
Dynamic Readings: 102 dB[1]
Maximum Input: 10 V
Noise Level: .16 mV
Equivalent Microphone Sensitivity:
re 1 V/Pa −29 dB[2]
Crest Factor: 3 dB at maximum input; can handle individual events.
Sample Rate: 50 kHz single channel 25 kHz dual channel

Power Supply:	120 V ac	Internal rechargeable batteries	12 V dc external
Endurance:	–	4 hours	3 days

[1]Up to 80-dB correction factor can be added.
[2]With 20 dB of gain in B&K 4921 and 17 dB of correction.

CERL/EPA

Data Storage: Magnetic tape
Calculation: Programmable calculator
Results Available: L_{eq}, L_{dn}, S.D., selected L_n, data bins.
Time to Analyze a 1-Hour Block: 1/2 minute for printout
Electrical Inputs: 120-dB scale NOTE: Any scale may be entered from the keyboard
Weightings: A, C, D, flat
Maximum Readings: Depends on scale entered
Dynamic Range: 80 dB
Maximum Input: 10 V
Noise Level: 1 mV
Equivalent Microphone Sensitivity:
re 1 V/Pa −29 dB[1]
Crest Factor: 14 dB
Sample Rate: 10 samples/second and slower
Power Supply: 120 V ac
Endurance: –

[1]With 23 dB of gain in B&K 4921

Digital Acoustics Model DA603
Incremental Noise Data Acquisition Unit

Data Storage: Magnetic tape
Calculation: Programmable calculator
Results Available: L_{eq}, NPL, S.D., selected L_n
Time to Analyze a 1-Hour Block: 3 minutes with data rate 1/second; lower sample rates take less time and vice versa

Electrical Inputs:	with calibration switches at minimum	with calibration switches at maximum
Weightings:	A or flat	A or flat
Maximum Readings:	143 dB	143 dB
Dynamic Range:	123 dB	61 dB
Maximum Input:	12 V	8.9 mV
Noise Level:	8.5 μV	7.5 μV
Equivalent Microphone Sensitivity: re 1 V/Pa	−27 dB	−90 dB
Crest Factor:	30 dB	30 dB

Sample Rate: 4, 2, 1 sample/second, and 2, 4, 8, 10, 32 seconds/sample
Power Supply: Internal rechargeable battery
Endurance: 3 days

General Radio Model 1945
Community Noise Analyzer

Data Storage: Internal memory
Calculation: Internal computation
Results Available: L_{eq}, L_{dn}, selected L_n, HUD levels
Time to Analyze a 1-Hour Block: 1 1/2 minutes–varies with number of L_n's examined

	Microphone	Auxiliary
Electrical Inputs:	Microphone	Auxiliary
Weightings:	A,C, flat	A, C, flat
Maximum Readings:	120 dB	120 dB
Dynamic Range:	98 dB	98 dB
Maximum Input:	.13 V	.51 V
Noise Level:	1.6 μV	6.5 μV
Equivalent Microphone Sensitivity: re 1 V/Pa	–44 dB	–32 dB

Crest Factor: At least 14 dB at maximum reading
Sample Rate: 10 samples/second
Power Supply: 6 "D" cells
Endurance: 3 days

Laboratory Equipment Model 2010B
Digital Acoustical Data Acquisition System

Data Storage: Magnetic tape
Calculation: Minicomputer at manufacturer's facility
Results Available: L_n, L_{eq}, HNL, L_{dn}, L_{NP}, CNEL
Time to Analyze a 1-Hour Block: N/A
Electrical Inputs: Microphone
Weightings: A, C, flat
Maximum Readings: 125 dB
Dynamic Range: 100 dB NOTE: Not measured. Used manufacturer's data sheet value.
Maximum Input: 1.8 V NOTE: Not measured. Used manufacturer's data sheet value.
Noise Level: 18μV NOTE: Not measured. Used manufacturer's data sheet value.
Equivalent Microphone Sensitivity:
re 1 V/Pa –26 dB
Crest Factor: Not measured
Sample Rate: .5, 1, and 10 seconds per sample

Power Supply:	120 V ac	10 to 18 V dc external supply	Internal battery
Endurance:	–	–	8 hours

Metrosonics Model dB-602
Sound Level Analyzer

Data Storage: Internal memory

Calculation: Internal computation. NOTE 1: Unit tested did *not have* L_{eq} *option installed. NOTE 2: the stored data* can be read by a Wang 600 programmable calculator for further processing.

Results Available: Arbitrary L_n values in 1-dB steps.

Time to Analyze a 1-Hour Block: 1 1/2 minutes. Time varies with number of L_n's examined.

Electrical Inputs:	130-dB range[1] (cw)[2]	130-dB range (ccw)[2]	Microphone A[3]
Weightings:	flat	flat	A
Maximum Readings:	149 dB	149 dB	119 dB
Dynamic Range:	87 dB	99 dB	87 dB
Maximum Input:	4.38 V	26.5 V	0.18 V
Noise Level:	.20 mV	.30 mV	8 μV
Equivalent Microphone Sensitivity: re 1 V/Pa	−26 dB	−42 dB	−40 dB
Crest Factor:	10 dB		

Sample Rate: 1 sample/second (set at factory; others are available upon request)

Power Supply:	120 V ac	Internal rechargeable battery	External 12 V dc
Endurance:	–	2 days	–

[1]Range switch only changes displayed value.

[2]cw and ccw refer to the position of the calibration potentiometer.

[3]Microphone B same as Microphone A but display reads 10 dB higher.

Tracor
Environmental Noise Monitor

Data Storage: Magnetic tape

Calculation: Minicomputer (at manufacturer's facility)

Results Available: L_{eq}, CNEL, selected L_n

Time to Analyze a 1-Hour Block: N/A

Electrical Inputs:	130-dB Range	100-dB Range
Weightings	A	A
Maximum Readings:	129 dB	99 dB
Dynamic Range:	85 dB	69 dB
Maximum Input:	.36 V	11 mV
Noise Level:	20 μV	4 μV
Equivalent Microphone Sensitivity: re 1 V/Pa	−44 dB	−44 dB

Crest Factor: N/A. Does not have RMS detector.

Sample Rate: 1/second

Power Supply: External 12-V auto battery

Endurance: 2 days

NOTE: This unit was developed for the manufacturer's internal use.

ENA

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